

Validation of AMSR Rainfall Using an Airborne Precipitation Radar (PR-2)

Progress Report
March 31, 2004

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Introduction

The Advanced Microwave Scanning Radiometer - Earth Observing System (AMSR-E) is a mission instrument launched aboard NASA's Aqua Satellite on 4 May 2002. AMSR-E validation studies linked to rainfall experiments are designed to evaluate the accuracy of AMSR-E precipitation data. In January and February 2003, the Airborne Second Generation Precipitation Radar (APR-2) collected data in the Wakasa Bay AMSR-E validation campaign over the sea of Japan on board a NASA P-3 aircraft. Data were collected on all P-3 flights that encountered precipitation. APR-2 collected data at 13.405 and 35.605 GHz in a downward-looking, cross-track scanning geometry. The experiment was designed to validate the AMSR-E shallow rain and snow retrievals, and to extend the precipitation database needed to implement a physical validation strategy.

The vast majority of the effort in this task has been the integration of the APR-2 instrument with the P-3 aircraft, the collection of the data, and most recently, the processing of the data and delivery to the NSIDC data archive in Boulder CO. Indeed, this last year since the field campaign has been devoted to a detailed analysis of the data and its quality. One of the major challenges has been proper estimation of the P-3 position and orientation and correction of motion effects in the APR-2 data. This is due to the greater sensitivity of this aircraft to environmental winds than the DC-8 platform previously used for APR-2. The end result of this work is a high quality dataset for use in AMSR validation. A preliminary version of the data was released in October 2003. This was further refined in V 2.0, released in February 2004.

APR-2 Data Collection

Table 1 lists the flights of the P-3 during the Wakasa Bay Experiment.

Table 1. APR-2 Operation During Wakasa Bay Experiment

Flight	Date	Comments
1	1/14/03	APR-2 in Engineering Operations (testing and optimization of configuration) - one file of science data available in this release
2	1/15/03	Mainly snow over land
3	1/19/03	Rainfall over ocean - APR-2 turned off during low altitude lags.
4	1/21/03	Mainly rainfall over ocean, some snow
5	1/23/03	Widespread rain and squall line over ocean
6	1/26/03	Clear air flight for PSR calibration, but APR-2 not turned on
7	1/27/03	Widespread rain over land
8	1/28/03	Scattered snow showers over land and ocean
9	1/29/03	Widespread snow over land and ocean
10	1/30/03	Snow showers over ocean - APR-2 in Engineering Operations after 0500 UTC
11	2/1/03	No precipitation - APR-2 mainly in Engineering Operations, no files of science data available in this release
12	2/3/03	Rainfall with varying freezing level

Data Processing

APR-2 acquires dual-polarized, Doppler data at both radar operating frequencies. A C-language program operates on these raw data and produces calibrated data at both frequencies. These data are referred to as Level 1A. Within this code, the raw powers are converted to radar reflectivity, and the lag-1 correlations are converted to Doppler velocity using the pulse-pair technique. The Level 1 A processing does not include aircraft navigation data. A second processing step, written in Matlab, integrates the navigation data with the calibrated radar data. As noted above, much of the effort during this past year has involved getting these data to be synchronized and properly correcting the radar data for platform motion. The Doppler and LDR at 35 GHz are both considered experimental and were not included in the standard Level 1 B product sent to the data archive. This product consists of the calibrated reflectivity at both 13.405 and 35.605 GHz, as well as the Doppler and linear depolarization ratio (LDR) at 13.405 GHz. Data are available via FTP in Hierarchical Data Format (HDF) and JPEG browse images.

APR-2 Quality Assessment

APR-2 data quality has been assessed by examining a number of engineering parameters related to the radar's stability and calibration. The observed minimum detectable reflectivity (Z) for APR-2 at both frequencies was derived from clear-air observations of the radar return signal and of the receiver noise floor. (In the Wakasa Bay experiment, no pulse was transmitted in ray #1 of each scan to measure receiver noise.) The values for both Ku-band and Ka-band are below 5 dBZ at 10 km range from the radar. Due to system non-linearities, the effective minimum detectable reflectivity was approximately 5 dBZ at 6 km range. The surface return, along with pulse compression sidelobes, can be seen at approximately 6 km range. The pulse compression sidelobes, rather than thermal noise, limit performance near the surface. Achieving such low pulse compression sidelobes required careful design of the transmit waveform and control of gain and phase errors.

Radar calibration can be verified using observations of the ocean surface. This technique has been used previously, since the ocean backscatter near nadir is well known, especially near 10 degrees incidence, where sensitivity to wind speed is a minimum. Ocean backscatter at Ka-band is not as well characterized, although models show similar behavior to the Ku-band. At Ka-band, the reflectivity in very light rain should be nearly identical to that at Ku-band, since Rayleigh scattering should apply at both frequencies.

Observations of the ocean surface with APR-2 show a cross section near 7 dB, which is close to previous measurements. Ocean backscatter comparisons with surface reflectivities calculated with Geophysical Model Function (GMF) or from TRMM/PR measurements indicate a bias of less ~0.5 dBZ, but strong winds and clouds undetected by APR-2 are possible contributors for this bias at Ku band. In-depth analysis is required to further refine calibration. The Ka-band data have reflectivities within about 1 dB of the Ku-band reflectivities in light rain. Surface Doppler measurements can be compared with Doppler calculated from the P-3 navigation parameters and the APR-2 antenna pointing. Such a comparison indicates the bias between the observed and calculated Doppler is very small.

APR-2 operated on eleven out of the twelve atmospheric science flights of the NASA P-3 aircraft during the Wakasa Bay Experiment (WBE). It did not operate on flight number 6, a clear-air flight, or on the sea-ice flights into Russian air space. Parameters under operator control were set to the same values throughout the experiment, with the exception of the receive window attenuation, which varies with surface brightness. The pulse length was always set to 10 microseconds and the PRF to 5000 Hz. The number of pulses averaged in real time was 250, equivalent to about 60 independent pulses. The elevation angle of the antenna (along-track angle) was set during flight to maintain a near-zero Doppler from the surface, minimizing platform motion contamination to the measured Doppler from precipitation. The platform motion was estimated from the surface and subtracted during ground processing. The azimuth scan limits were about +/- 25 degrees.

For the flights on January 14th and 30th and February 1st, different radar bit-processor configurations were tested, so only a limited amount of the data from these flights have been processed for this release of the data.

Science Analyses with APR-2 Data

The Wakasa Bay Experiment is designed to validate the AMSR and AMSR-E shallow rainfall and snowfall retrieval capabilities, and to extend the database of rainfall properties needed to implement a comprehensive physical validation scheme. Other instruments aboard the P3 aircraft include a 94-GHz airborne cloud radar (ACR); a passive microwave sensor (PSR) that simulates the AMSR observations; a microwave radiometer (MIR) covering from 90 to 340 GHz; and an upward looking radiometer at 21 and 37 GHz (AMMR). Four studies were started thanks to the availability of APR-2 data from the Wakasa Bay Experiment: high resolution analysis of the melting layer of precipitation and its impact on spaceborne retrieval algorithms, multipolarimetric characterization of the multiple scattering by intense precipitation and its correction, and study of the millimeter-wave radiometric measurements of frozen hydrometeors through the analysis of APR-2, ACR and MIR measurements, triple-frequency measurements from the APR-2 and ACR of light shallow precipitation and their implications on the Particle Size Distribution..

On 8 of the flights, APR-2 observed stratiform rain and the associated melting layer, whose impact on passive remote sensing of precipitation is one of the specific issues addressed by this experiment. The signatures of the melting layer on APR-2 measurements from four flights were presented and discussed [1] and one example is shown in Figure 1. A Melting Layer Detection Algorithm that takes advantage of APR-2 high vertical resolution (37 m) and of its multiparametric capabilities was developed for this purpose (it uses the vertical profiles of reflectivity Z_{14} and Z_{35} , Doppler velocity v_{14} , and Linear Depolarization Ratios LDR_{14} and LDR_{35}). Overall, the conclusions previously drawn from analysis of the NASA/JPL ARMAR data from TOGA COARE were confirmed by the Wakasa Bay Experiment. In particular it was observed a) the positive correlation between the Z_{14} peak in brightband Ku and brightband thickness ($\sim +0.7$); b) the negative altitude offset of the peak in LDR with respect to the peak in Z_{14} (observed mean offset = -70 m, negatively correlated with Z_{14} peak). Furthermore, a strong (~ 0.8) correlation of the altitude and thickness of the LDR signature was observed with the area of vertical acceleration of the particles. This seems to confirm the interpretation offered in that study for the possible cause of the negative altitude offset. On the other hand, the altitude of Ka band LDR peak was in general between that of the reflectivity peak and the Ku band LDR peak, and it showed a weaker correlation with the Z_{14} peak). This might be due to the

fact that smaller particles reach their terminal velocity higher than the larger particles; and c) ice reflectivity above the bright band is less than rain reflectivity below; the difference becomes more negative with increasing rain reflectivity.

These results will be used to verify the validity of simplified models of the melting layer used to estimate its radar and radiometric signatures and their effect on precipitation retrieval algorithms.

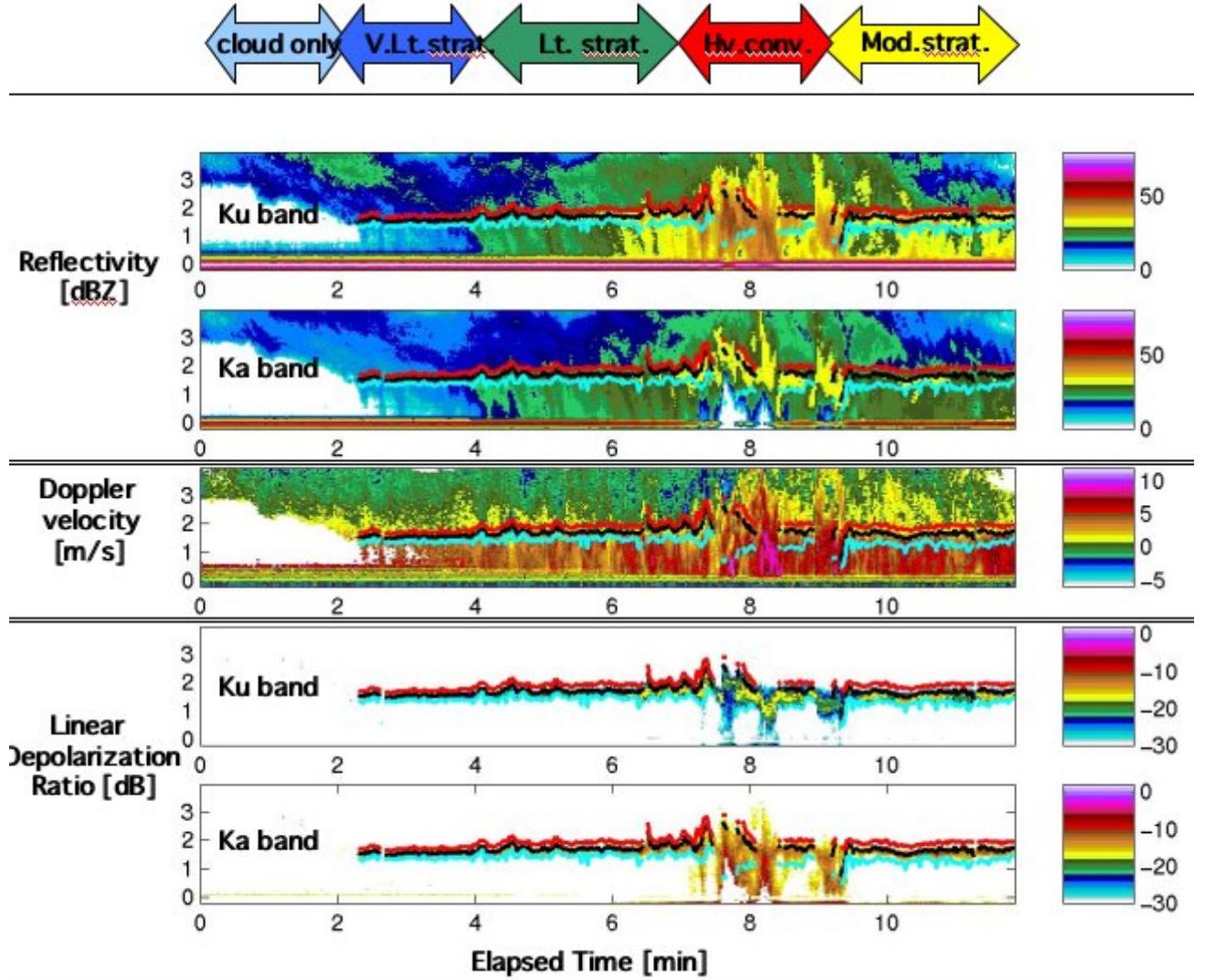


Fig 1. Stratiform system with embedded convection observed by APR-2 on Jan 19th, 2003. Classification of precipitation and melting layer higher (red) and lower (cyan) boundaries are shown.

Electromagnetic modeling of multiple scattering from precipitation started in Nov. 2003 in order to assess its impact on millimeter wave radar measurements. The model will be used to validate the hypothesis that multiple scattering is generating LDR signatures such as that visible in Fig. 1, at the 8th minute, in the LDR Ka band channel. The model will be also be applied to verify whether the LDR signatures at two frequencies can significantly contribute to quantify and correct for the contribution of multiple scattering in reflectivity measurements. Preliminary results obtained through a simplified plane-wave, time-independent model have been obtained and their analysis is in progress.

A study performed at the University of Washington analyzes the millimeter-wave radiometric measurements of frozen hydrometeors. Especially, observations provided by Microwave Imaging Radiometer (MIR) covering from 90 to 340 GHz, the dual frequency Airborne Precipitation Radar (APR-2) operating at 14 and 35 GHz, and the Airborne Cloud Radar (ACR) operating at 94 GHz during January 29th 2003 are investigated in this study. The MM5 cloud simulation is employed to provide temperature and humidity profiles for the radiative transfer calculations. Parameterizations to represent the electromagnetic scattering properties of snow at millimeter-wave frequencies are applied to the hydrometeor profiles derived by airborne radar measurements. Calculated brightness temperatures, radar reflectivities are compared with the millimeter-wave measurements.

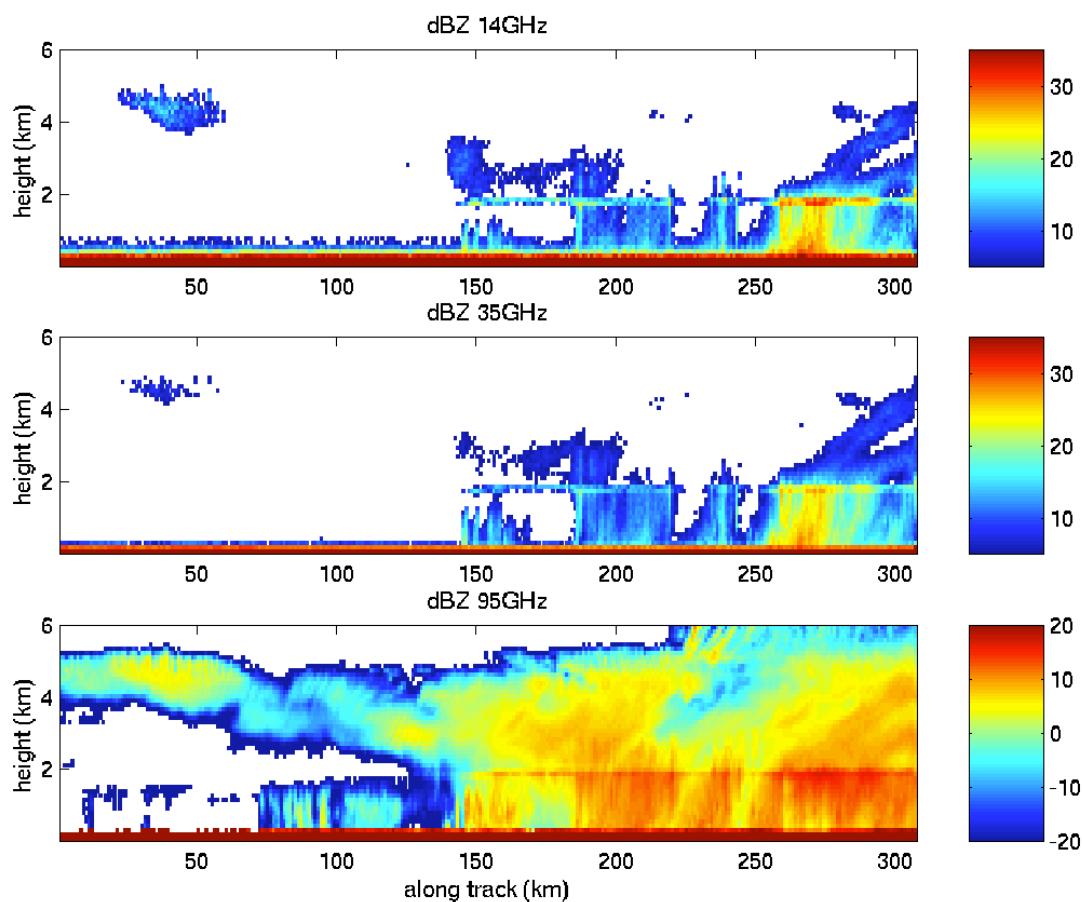


Fig 2. Triple frequency (14,35,95) GHz along-track images of a light precipitation case, from the APR-2 and ACR radar systems on the 27th of Jan 2003.

An initial study has been undertaken using data from both the APR-2 and the University of Massachusetts/JPL Airborne Cloud Radar (ACR) to study shallow light precipitation and the implications on the Particle Size Distributions of such types of precipitation. Measurements for a flight line on the 27th of Jan 2003 for the two instruments have been collocated and interpolated onto a common resolution grid for study, see Fig 2. This case was chosen as it encompasses a transition from clouds to light precipitation and finally to bands of moderate intensity rainfall. Figure 3, shows scatter plots of reflectivity vs. difference in reflectivity for the three frequency combinations for the APR-2 and ACR instruments for range bins at and just below the Bright Band (BB). The majority of the points for the 95 GHz and 35 GHz channels are in the Mie scattering regime rather than the Rayleigh, shown by the fact that there is a significant reflectivity difference (Y axis in the scatter plots). Where as, for the 14 GHz / 35 GHz plots at the BB there is a difference in reflectivity between the two channels, mostly likely large low density frozen or semi frozen hydrometeors, but below the BB there is no longer a significant reflectivity difference. The particles are mostly likely smaller liquid particles in the Rayleigh scattering regime. This has important consequences on the Particle Size Distributions used for relations that are suitable for retrievals in light shallow precipitation and show that care must be taken as to the maximum size of particles used to calculate the retrieval relations.

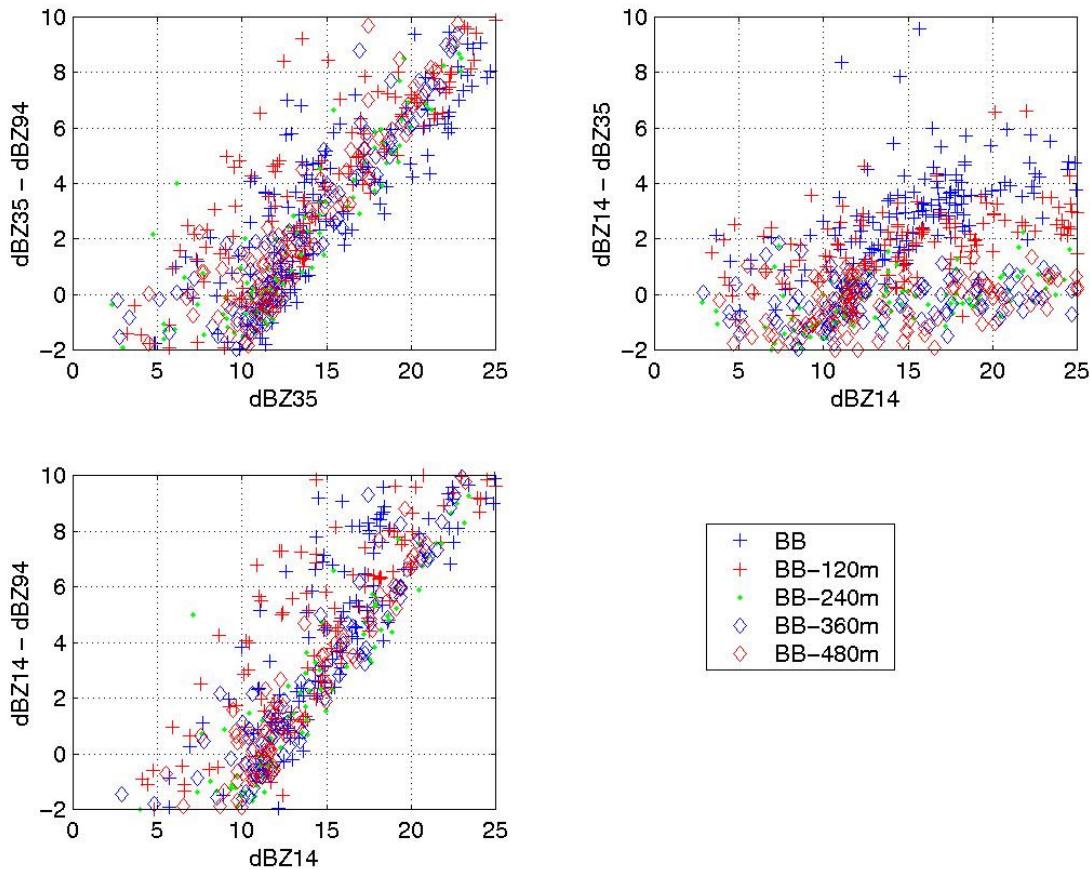


Fig 3. Scatter plots of reflectivity vs. difference in reflectivity for the frequency combinations of the APR-2 and ACR radar systems at and just below the Bright Band (BB), for the 27th of Jan 2003 case.

Publications

- Tanelli S., J. Meagher, S.L. Durden and E.Im, 2003: Multiparametric airborne radar observations of the melting layer during the Wakasa Bay Experiment, *Proc. of the 31st Conf. on Radar Met.*, Seattle Aug. 6-12 2003, 33-34.
- Tanelli S., E. Im, S. L. Durden and J. Meagher, 2004: Rainfall and Snowfall Observations by the Airborne Dual-Frequency Precipitation Radar During the Wakasa Bay Experiment, submitted to IEEE Int'l Geoscience and Remote Sensing Symposium, Anchorage AK, Sept. 19-24, 2004.
- Tanelli S., J. Meagher, E. Im, Z. S. Haddad and S. Kobayashi, 2004: Precipitation Classification and Retrieval from Multiparametric Airborne Precipitation Radar Measurements, submitted to IEEE Int'l Geoscience and Remote Sensing Symposium, Anchorage AK, Sept. 19-24, 2004.
- Kim M.-J. , J A. Weinman, D.-E. Chang, J. R. Wang, S. Tanelli, J. Roman, and S. Sekelsky , 2004: Analysis of Millimeter-wave Measurements of Frozen Hydrometeors during the 2003 Wakasa Bay Field Experiment, submitted to IEEE Int'l Geoscience and Remote Sensing Symposium, Anchorage AK, Sept. 19-24, 2004.